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TITLE: Method of distortion correction for gradient non-linearities in nuclear magnetic resonance tomography apparatus

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Brief Summary Text (5):
As is known, inhomogeneities in the basic magnetic field and non-linearities of gradient fields lead to image distortions if there are no corrective or preventative measures in the standard MR imaging sequences. Pulse sequences currently utilized are generally based on a technique referred to as the "Spin Warp" method as disclosed, for example, in U.S. Pat. No. 4,706,025. Each nuclear magnetic resonance signal is thereby phase-encoded in at least one direction before the readout and is frequency-encoded in another direction by a readout gradient during readout. A number of differently phase-encoded nuclear magnetic resonance signals are acquired. The nuclear magnetic resonance signals are sampled, digitized onto a grid in the k-space and entered into a raw data matrix in the k-space. A Fourier transformation in the phase-encoding direction as well as in the frequency-encoding direction is implemented in the raw data matrix for image acquisition.

Brief Summary Text (6):
A number of correction methods have been described in the literature wherein image distortions due to non-uniform magnetic fields are corrected by an after-processing (post-processing) of the raw data or of the calculated image data, for example, the article by J. Weis, L. Budinski, "Simulation of the Influence of Magnetic Field Inhomogeneity and Distortion Correction in MR Imaging" in Magnetic Resonance Imaging, Vol. 8, pp. 483-489, 1990. It is known from this reference to correct image distortions by after-processing of an image acquired in a conventional way (i.e. with at least two-dimensional Fourier transformation). The information about the magnetic field inhomogeneities that is thereby required, i.e. about the course of the basic magnetic field, is thereby acquired from the phase of separately registered spin echo images.

Brief Summary Text (8):
If only inhomogeneities of the basic magnetic field are taken into consideration, these are relatively uncritical in the phase-encoding direction since the only concern is signal differences between the individual phase-encoding steps. In the direction of the readout gradient, however, the superimposition of the readout gradient with basic field inhomogeneities leads to distortions. In a method according to German OS 44 16 363, a conventional Fourier transformation is therefore implemented in the phase-encoding direction, whereas a generalized Fresnel transformation (wherein a previously identified location dependency of the basic magnetic field in readout direction is taken into account) is implemented in the readout direction.

Brief Summary Text (9):
If not only inhomogeneities of the basic magnetic field, but also non-linearities of the phase-encoding gradient are to be taken into consideration, then a correction must also be implemented in the phase-encoding direction. The outlay for

the gradient coils can be reduced when a non-linear field course of the phase-encoding gradient is allowed in the examination field. A strong inducement to utilize non-linear gradients, or even a necessity to do so, exists in the case of the echo planar imaging (EPI) method. As is known, high-amplitude gradients must be switched extremely fast in EPI. This can lead to undesirable physiological stimulations of the patient, even pain in the extreme case. The problem is most serious at the edge of or at the outside the examination field since the largest gradient field swing occurs at those regions. This problem can thus be solved by causing the gradients to flatten toward the edge of the examination field, i.e., they are non-linear.

Drawing Description Text (4):
FIG. 3 shows the location shift of a pixel due to gradient non-linearities.

Detailed Description Text (8):
For reconstruction of each and every pixel x,y, thus, the pixel x',y' to which the location shift occurred must first be found. This would be possible without further difficulty on the basis of Equations 5 and 6:

Detailed Description Text (13):
As shown in FIG. 5, a smearing of the pixel x,y in the diagonal direction ensues in the present example due to the gradient non-linearities, i.e. the shifted pixel x',y' has the form of a diagonal bar shown black in FIG. 5. The original pixel x,y is thus expanded onto a number of pixels in the distorted image. In the aforementioned correction, one proceeds on the basis of a spread of the pixel onto the region .DELTA.gx, .DELTA.gy, i.e. the entire rectangle shown shaded is imaged into the pixel x,y. This leads to the above-presented inadequacies of the reconstruction.

Detailed Description Text (31):
G.sub.P (t')=momentary value of the phase-encoding gradient.

CLAIMS:

3. A method according to claim 1, wherein the intensity of the image pixel at the actual location (x,y) is determined by weighted summation of the intensities of the pixels in a region around the measured location (x',y'), said the region covering an enlargement of a pixel due to the distortion.

8. A method according to claim 7, wherein the intensity of the image pixel at the actual location (x,y) is determined by weighted summation of the intensities of the pixels in a region around the measured location (x',y'), said the region covering an enlargement of a pixel due to the distortion.